Dual frequency comb spectroscopy and atmospheric modeling for the detection of methane leaks at oil and gas production sites

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Abstract: We present the development of a dual frequency comb spectrometer (DCS) system with the potential to locate and size methane leaks from oil and gas production sites over extended periods of time. The DCS system has been optimized for broadband high-precision measurements of methane over kilometer scale open paths. These measurements are coupled with an atmospheric inversion which utilizes local meteorology and a high resolution fluid dynamics simulation in order to retrieve methane leak locations and leak rates. Initial demonstrations of the instrument and techniques will be presented. In the long term, the system will be deployed at the Boulder Atmospheric Observatory (BAO) site, which is optimal for assessing the measurement and inversion methods under realistic conditions, e.g., highly variable background and high oil and gas production site density.

Keywords: Phase coherent lasers, Frequency combs, Spectroscopy, Atmospheric inversions

1. Introduction

Methane is an important greenhouse with both natural and anthropogenic sources. Uncertainty on the impact of anthropogenic methane emissions on climate change largely derives from inconsistencies in reported emission rates from many of the sources. According to the US Environmental Protection Agency (US EPA), anthropogenic methane emissions are reported to compose up to 60% of total global emissions [1], of which 33% comes from oil and natural gas (OG) production efforts [2]. Characterizing methane emissions from OG production sites is an area of increasing research interest in the US due to large increases in US methane production activity.

Dual frequency comb spectrometers (DCS) present a powerful analytical tool that are well suited for monitoring atmospheric methane and other trace gases due to their broadband nature, high spectral resolution, and fast data acquisition rate [3-10]. We have demonstrated that DCS instrumentation can operate over kilometer scale open-paths and measure multiple atmospheric trace gases with high precision [7]. Building from this work, we have a developed a DCS specifically to address the issue of monitoring OG production sites to locate and size methane leaks.

In order to derive a leak location and rate from the path integrated concentration measurements (the final data product from the DCS instrument), we are concurrently developing an atmospheric inversion that couples the DCS measurements with a high resolution fluid dynamics model and local meteorological data. Simulations with this modeling system using synthetic data have shown that we should be able to locate leaks to individual well pads and accurately determine leak rates with a fairly conservative precision (for a DCS instrument) of 4 ppb*km for methane.

Field testing of the entire system is planned to take place starting in the Summer of 2016 at the Boulder Atmospheric Observatory (BAO) located in Erie, CO (~20 km east of Boulder, CO). Currently, a majority of the inversion modeling simulations have utilized topography, meteorology, and background methane measurements from this site in order to most accurately represent measurement conditions during field testing.

2. DCS Characterization

Given the technological advances between the proof-of-concept DCS and the system presented here, a characterization of instrument performance for the newer DCS compared to the older instrument was warranted. The characterization testing has taken place at the National Institute of Standards and Technology (NIST) Boulder, which has a ~2 km open path measurement site that spans from the main NIST campus to the Koehler Mesa located directly to the west of the main campus. The 2 km link is an ideal test domain in that it enables open path measurements while allowing the DCS system to remain in a relatively controlled environment. Additionally, the proof-of-concept measurements made with an older version of the DCS instrument [8] were taken over this same path; thus allowing a reasonable comparison between instruments and quantification of improvements in the DCS instrumentation performance.

The proof-of-concept measurements showed good agreement with a Picarro multi-gas analyzer located at approximately the half-way point between the DCS launch location and the retroreflectors and was able to reach a methane precision of 6 ppb*km with 5 min averaging time [8]. Using a similar testing configuration as the proof-of-concept measurements, we were able to assess these same criteria using the newer version DCS system. We were able to reach a measurement precision of ~4 ppb*km with 90 s averaging. The precision floor reached by both of these measurement sets is determined to be limited by atmospheric variability of methane. In order to test instrument precision capability over open paths while minimizing this limitation, further tests were performed over a shorter path length (~400 m) with higher return power and under windier conditions (which results in low atmospheric trace gas concentration variability). These showed the DCS capable of reaching a precision level of ~1 ppb*km in ~100 s. Figure 1 shows Allan Deviation plots for the new DCS instrument from measurements over the full 2 km path (brown trace) and over the shorter path (red trace), as well as the data from the proof-of-concept measurements (blue trace). The grey dashed lines represent idealized curves in the absence of any atmospheric limitations; the top trace represents the proof-of-concept measurements and the bottom trace is for the newer DCS design. Better DCS performance from the new design is attributed to an optimized optical launch/receive configuration (telescope transceiver, detector, retroreflector, etc.) and the higher data acquisition rate, which is related to the lower comb tooth density of the new DCS instrument.

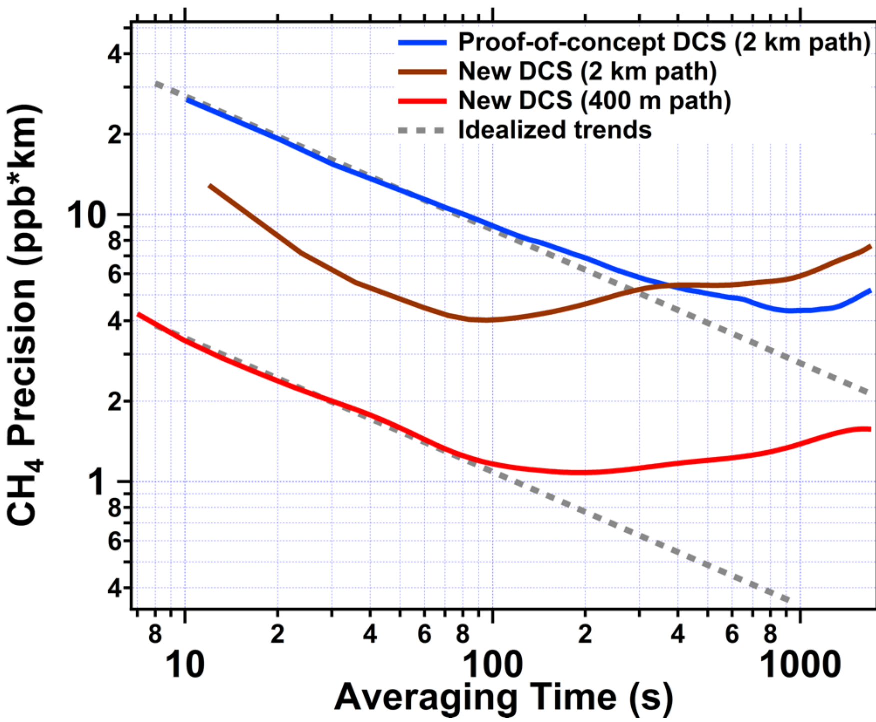

Figure 1. Allan Deviation plots for DCS system

3. Atmospheric Inversion

While the portable DCS was under development, the transport modeling and inversion schemes were developed and tested using synthetic data coupled with actual meteorological measurements taken at the field site (BAO). The synthetic data tests are able to determine the DCS system requirements and optimal measurement configurations (including site layout and measurement schemes). Methane measurements taken with a Picarro multi-gas analyzer as part of the Front Range Air Pollution and Photochemistry Experiment (FRAPPE) field campaign during the summer 2014 at the BAO tower site have been incorporated in these modeling studies to act as a way to add realistic background variability to the simulations. Additionally, wind speed and direction data taken during the same time at the BAO tower are being used to ensure the most accurate representation of the atmospheric state during the time of the methane measurements.

Several measurement site layouts, i.e. retroreflector placement relative to the DCS and wells, have been found to produce positive results in the inversion, which gives an indication that there is some flexibility when setting up the field tests. Additionally, different measurements schemes are being tested to ensure optimal and efficient sampling of the retroreflectors under varying wind conditions which is an important consideration especially when monitoring many different OG production sites.

The modeling runs have determined that an instrument precision of at least 4 ppb*km is needed in order to accurately locate and size methane leaks at the measurement site, and when using this criterion coupled with the realistic representation of atmospheric state and background methane variations described above, we find that the DCS should be fully capable of locating methane leaks to a single well-pad and estimating the leak rate. Figure 2 presents the results from one of the synthetic data modeling runs in which the simulated measurements located 2 leaks in a domain containing 52 OG production sites. In Fig. 2, blue dots show “actual” leak locations (on the x-axis and y-axis) and strengths (on the z-axis). Green dots show recovered leak locations and strengths, with error bars indicating 2 standard deviations. The recovered leak on the domain boundary shows influence of near-field outside sources and is off the z-axis scale.

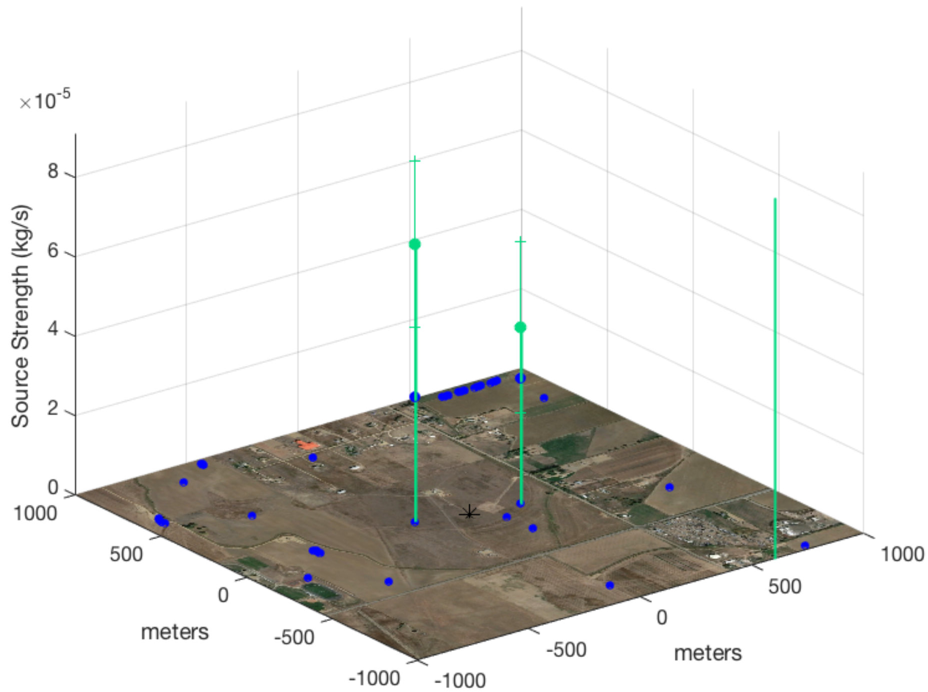

Figure 2. Inversion results using synthetic data

4. Summary

We present the development of a dual frequency comb spectrometer and atmospheric modeling/inversion technique that will facilitate the monitoring of oil and natural gas production sites for methane leaks on a regional scale. The original demonstration of the DCS proved that this instrument represents a powerful tool for monitoring multiple atmospheric trace gases over kilometer scale open paths. Building from this work, we are now able to decouple the DCS from the laboratory and operate it in a field environment at higher precision. The modeling and inversion techniques being developed allow for the derivation of leak location and rate using only path integrated concentration measurements of methane from the DCS and local meteorological data. Deploying this system in areas with high densities of OG operations would enable the simultaneous monitoring of numerous production sites and facilitate the quantification of both leak frequency and rates over extended periods of time.

5. References

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